The source regions of the fast solar wind

L. Teriaca

Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany

Contact: teriaca@mps.mpg.de

It is more than 30 years that comparisons of the solar X-ray flux and *in situ* measurements of particle speeds, showed coronal holes to be the source regions of the fast solar wind (Krieger et al. 1973, Solar Phys. 29, 505). More recently this result was confirmed by Ulysses wind speed data during polar passages, showing a clear correlation with the large polar coronal holes (CHs) characterizing the Sun at activity minimum (McComas et al. 1998, JGR 103, 1955). However, the precise identification of the structures (within a CH) from which the fast wind originates is still matter of debate.

White light images of the minimum corona during eclipses reveal linear structures, called *plumes*, rooted in coronal holes and extending towards the interplanetary space. Observations in vacuum ultraviolet (VUV: 16 – 200 nm) lines formed at temperatures around 0.8 MK allow the study of the plume roots on the disk where their brightness is enhanced with respect to the background CH emission from *interplume* areas. Despite plumes are the dominant structures within CHs, interplume regions have been suspected to be the source regions of the fast wind, starting a strong debate yet not solved. Theoretical models give opposite indications. Del Zanna et al. (1997, A&A 318, 963) and Casalbuoni et al. (1999, JGR 104, 9947) show that the outflow speed in plumes can be larger or smaller than in the ambient depending on the temperature and Alfvén wave flux assumed in the two regions.

From VUV spectroscopy plumes are known to be denser and cooler than the surrounding interplume regions (e.g., Wilhelm 2006, A&A, in press). Spectral lines are observed to be broader in interplumes (e.g., Wilhelm, 2006; A&A, in press; Banerjee et al. 2000, Solar Phys. 194, 43) hinting to preferential energy deposition in these structures. The analysis of the chemical composition could provide a tool to establish whether plumes or interplumes contribute significantly to the fast wind. In fact, a chemical composition substantially different from that measured *in situ* in the fast wind would indicate that the observed region does not provide a significant mass flux. However, recent observations seem converging towards small or no relevant difference between plumes and interplumes (e.g., Del Zanna et al. 2003, A&A 398, 743).

Of course, the most direct way to solve this issue would be to determine the velocity field at the base of the corona in both regions. The outflow velocities can be inferred from off-limb spectra using the Doppler Dimming technique (e.g., Noci et al. 1987, ApJ 315, 906). However, the technique is strongly dependent on the local electron density and on the adopted geometry of the coronal structures. Two studies of plumes and interplumes below 1.2 solar radii, both based on SUMER data, gave results that were comparable for the interplume but opposite for the plumes. Teriaca et al. (2003, ApJ 588, 566) found the results to be consistent with a negligible outflow in plumes, while Gabriel et al. (2003, ApJ 589, 623) found outflows to be larger in plumes than in interplumes.

Line of sight (LOS) velocities can be measured from Doppler shifts. This method does not rely upon assumptions on the local plasma parameters but depends on the observing geometry. In fact, it is necessary to correct for the angle between the LOS and the direction of the magnetic field lines (roughly radial near to the surface). This is particularly difficult when observing the solar poles from the ecliptic plane. Wilhelm et al. (2000, A&A 353, 749) measured LOS velocities of about -3 km s^{-1} in He I and Ne VIII on a polar coronal cole using the SUMER spectrometer. Although these measurements are close to the limit of SUMER velocity resolution (between 1 and 2 km s^{-1}), they clearly indicate that larger outflows arise from darker areas. The measured values lead to an average outflow velocity of −14 km s^{-1} when considering an average angle of 80° between the LOS and the direction of the field. A very similar result was obtained in an equatorial coronal hole (where the observing geometry is much more favorable) by Xia et al. (2003, A&A 399, L5), finding an average outflow speed of −7.5 km s^{-1} with larger outflows from the darker areas.

Observations performed out of the ecliptic plane could greatly improve and extend these results. This possibility will be offered by the Solar Orbiter mission, when the spacecraft will climb up to 31° above the ecliptic plane during the extended phase (up to 25° already during the science phase). Under these conditions a radial flow from the pole would offer a LOS component of about 50% of the outflow speed, allowing its precise measurement. Moreover, the mission features a vector magnetograph that will obtain for the first time measurements of the photospheric polar magnetic field, leading to the construction of reliable extrapolations of the coronal field to be compared with the velocity and radiance maps.

EUS instrument requirements

1. Emission line requirements

A spectral line formed at the base of the corona, at a temperature such that the emission is prevalently from open regions but also not so high that the line is too weak in CHs. In fact, Stucki et al. (2000, A&A 363, 1145) report that only lines with a formation temperature above 5×10^5 K appear blueshifted in CHs. The ideal line would be the Ne VIII 77.0 nm (band 6). Its contribution function peaks at 6.3×10^5 K with an extended tail towards higher temperatures. Its CH radiance is, on average, about 2.5 times weaker than on the quiet Sun, compared to the ≥25 drop of the Mg X 62.5 nm line (T = 1 MK) (Vernazza & Reeves, 1978, ApJS 37, 485).
Additional lines, if allowed by telemetry constrains, may provide precious information on the structure and dynamics of the underlying chromosphere and transition region. Lines could be chosen among H I Lyman-α 121.6 nm (2×10^4 K), Si III 120.6 (6×10^4 K), C III 97.7 nm (8×10^4 K), O IV 79.0 nm (1.5×10^5 K) and O VI 103.2 nm (3×10^5 K).

2. Spectral resolution requirements

It must be sufficient to measure velocities down to 1 or 2 km s^{-1}. Sub-pixel determination of the line position can be achieved by Gaussian fitting. At 77.0 nm, 2 km s^{-1} in 1/10 of pixel would require 0.005 nm/pixel, that can be considered as an upper limit.

3. Spatial coverage

The raster should cover a large sector of a polar CH, including quiet Sun areas towards disk centre and above-the-limb areas (the latter for wavelength determination). This leads to an observed area around 1400″×1400″ (at a spacecraft distance of 0.22 UA), opportunely centred (comparable with the 520″×300″ SUMER raster studied by Wilhelm et al. 2000, A&A 353, 749).

4. Time resolution (incl. count rates)

The Ne VIII line has an average CH radiance of 20 mW m^{-2} sr^{-1} (Vernazza & Reeves, 1978, ApJS 37, 485) from which count-rates between 3 and 13 count s^{-1} over the line can be expected. Simulations of Gaussian profiles with Poisson noise indicate that we need at least 50 count s^{-1} $pixel^{-1}$ at line peak to achieve an uncertainty level around 2 km s^{-1} (assuming a spectral scale of 0.005 nm/pixel and an instrumental profile with a FWHM of 2 pixels). This would require exposure times between 15 and 60 s.

5. Requirements for other instruments

Vector magnetograms from VIM plus EUI images in a 1 MK line (e.g., Fe IX 17.1 nm) and in a cold lime (H I Lyman α). FSI images of the large scale corona. There is no need for high cadence.

6. Other requirements

With a telemetry rate of 17 kbps and assuming 12 bits per pixel (from PDD version 5) and no compression, it takes 50 s to transmit a 50×1400 pixel^2 image, comparable with the required exposure time. If compression schemes are available, further spectral windows of the same size can be added, in a number equal to the adopted compression factor.

Relation to Solar Orbiter science goals

1. Determine the properties, dynamics and interactions of plasma, fields and particles in the near-Sun heliosphere

The study will determine the outflow wind speed at the base of the corona providing an important parameter for model of the fast wind and inner heliosphere.

2. Investigate the links between the solar surface, corona and inner heliosphere

The study will determine the structures from which the fast wind originates and resolve the strength and topology of the associated magnetic field.

3. Explore, at all latitudes, the energetics, dynamics and fine-scale structure of the Sun's magnetized atmosphere

Making use of the high latitude passages, it will study the poles of the Sun determining the strength and nature of the velocity field at the base of the corona.

4. Probe the solar dynamo by observing the Sun's high-latitude field, flows and seismic waves

N/A